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DOES CHLOROPHYLL DECOMPOSE CARBONIC ACID?

THE recent memoirs of Pringsheim, noticed in NATURE, vol. xxi. p. 85, by Mr. Vines ("Untersuchungen über das Chlorophyll," July and November, 1879) suggest very serious doubts as to the correctness of an inference which has crept, without the explicit consent of botanical physiologists, into the position of a fundamental doctrine of biological science. The recent excellent article in NATURE on "Vegetation under Electric Light," together with the discussion which took place at the Royal Society when Mr. Siemens's paper describing his experiments on plants under the influence of the electric light was read, tend still further to make it desirable to examine critically the claims which the inference alluded to has on our adhesion.

The inference in question is this, that the substance known as chlorophyll has the property of decomposing carbonic acid so as to fix the carbon and liberate a portion of the oxygen of that acid when in the presence of sun light. Accordingly it has been said that "Chlorophyll is the hand wherewith the organic world lays hold of the carbon of the inorganic world."

Vegetable physiologists are, however, careful not to commit themselves to such an assertion with regard to chlorophyll itself. The chlorophyll-grains or corpuscles are particles of protoplasm impregnated with chlorophyll much in the same way as the blood corpuscles and other tissues of animals are impregnated with hæmoglobin. It is one thing to attribute the decomposition of carbonic acid to "cells containing chlorophyll," or even to "chlorophyll corpuscles," and another thing to pass from such a wide statement to the definite ascription of the CO_2-decomposing property to the green-coloured substance chlorophyll.

It is perfectly true that by the method of concomitant variation we are led to a conclusion favourable to the *importance* of chlorophyll in this function. It is only by plants (or animals) containing chlorophyll and only in those parts of plants containing it that CO_2 is decomposed and oxygen liberated. Further, it appears that wherever chlorophyll is present *in a living organism* (even an animal) exposed to sunlight, the decomposition of CO_2 takes place. But whilst we are thus justified in *connecting* chlorophyll with the decomposition in question, any conclusion as to its sole efficiency, and accordingly any notion of a specific chemical activity on its part, is forbidden by two important facts: firstly, that living protoplasm is always present in intimate association with the chlorophyll when the decomposition of CO_2 is effected (forming the bulk of the chlorophyll-corpuscle); and secondly, that chlorophyll extracted from the chlorophyll-corpuscle and put to the test *in the absence of protoplasm* has hitherto not been shown to possess the power of effecting the specific decomposition sometimes attributed to it.

Very usually blood-red and leaf-green are placed side by side as complementary, not only in colour, but in function, the one active in oxidation and the special property of the animal, the other active in deoxidation and the special property of the plant. The pleasing agreement in difference which these two bodies apparently present has, no doubt, a real basis in fact, but the actual analogies between them have very possibly tempted the speculative biologist a little too far.[1] Both present remarkable and characteristic absorption spectra, both contain iron, both are diffused in the living albuminoid substance of organisms, the one of plants, the other of animals. Nevertheless a most important fact is true of hæmoglobin, which we have not ground for asserting with regard to chlorophyll, namely, that it can be extracted from the albuminoid substance with which it is associated, and then, when in a pure crystalline state, can be made to exhibit its peculiar property of combining with oxygen and again liberating that oxygen, just as it does in the living tissues.

On the other hand, the peculiar property which has been inferred for chlorophyll, namely, that of seizing the group CO from CO_2 and liberating O under the influence of sunlight, ceases altogether (as far as we know) when the chlorophyll is detached from the living protoplasm of an organism, and no effect of any kind upon CO_2 can be produced by its agency when thus isolated.

In reference to this objection to the assumed function of chlorophyll, it may be urged that the chlorophyll, when extracted from the chlorophyll-grain, is chemically altered by the solvent (alcohol or ether) used. To this it appears there is a complete answer. By chlorophyll we mean clearly enough the *green* substance present in the chlorophyll corpuscles. This substance is green in virtue of a specific absorption of light, which happens to be of such a nature as to cause definite well-marked bands of absorption in the spectrum of light which has passed through it. The solution obtained by appropriate treatment of green leaves gives precisely the same absorption-bands as does the green substance in the plant (the whole series being moved a very little to the blue end according to the known law that absorption-bands travel in that direction when a less dense solvent is substituted for a more dense one). Hence the *green* substance, to which we have to limit the term chlorophyll, may be inferred to exist unchanged in the solution.

The persistence of a complex banded absorption spectrum is, according to a large range of observations on the phenomena of absorption, a distinct proof of the persistence of chemical and molecular constitution. Those who are not prepared to admit this must, whilst thus disposing of a part of the evidence against the specific activity of chlorophyll, abandon the only evidence we have in favour of the specific activity of hæmoglobin, for it is upon the identity of the absorption-spectra of hæmoglobin, both in the organism and in the crystalline form, that we have to depend for the inference that the substance which we extract is the same substance as that which circulates in the blood and colours the muscles.

It cannot, however, be stated that a negative has been directly proved with regard to the supposed CO_2-decomposing property of chlorophyll. It is possible that chlorophyll, when extracted by solvents from the chlorophyll-corpuscles, may yet be shown to possess that property. The solvents themselves may, so long as they are present, exert an inhibitory effect. Whilst ether and alcohol may do so it

[1] As an example see Letourneau, "Biology:" Library of Contemporary Science, 1878, p. 97.

is possible that vegetable fats may be more propitious, or that some other solvents may be found more closely resembling the natural solvent of the chlorophyll-corpuscle than those at present known.

Apart, however, from the absence of sufficient evidence to warrant the assumption that chlorophyll has a specific chemical action on carbonic acid in the presence of sunlight, there have to be considered (1) facts connected with the part played by the sunlight which render it improbable that chlorophyll is thus concerned, and (2) facts which point to another use for chlorophyll, and one which involves that concomitance of chlorophyll with CO_2 decomposition which has been most strongly urged in favour of its supposed special property; (3) facts which suggest that such chemical activity as that sometimes attributed to chlorophyll is the special property of protoplasm, or rather of the higher members of that ever-ascending and descending series of albuminoid bodies occurring in organisms, of which series the theoretical apex is entitled to the name "protoplasm" (so far as the term can receive a chemical limitation).

1. If chlorophyll were the active agent in CO_2 decomposition under the influence of sunlight, we should expect the rays absorbed by chlorophyll to be those most efficient in promoting such decomposition. Such, it has been shown by Sachs and others, is *not* the case. Light which has traversed a solution of chlorophyll is still efficient in exciting the plant-cell (whatever part of the cell may be called into play) to the decomposition of CO_2 and liberation of O. It is true that the activity of light thus treated is diminished, but that is explained by the fact that the rays of the whole visible spectrum are some more, some less, capable of exciting the decomposition, and that the total amount of light transmitted is much diminished. The maximum evolution of oxygen by green plants is *not* in the red rays where chlorophyll most absorbs, nor in the indigo and violet which it also largely absorbs, but in the yellow, the orange, and the green, which it allows to pass entirely except for three very narrow and feeble absorption bands.

2. The action of light on the chemical motion of protoplasm (and we know of no changes in protoplasm which can be considered as other than chemical) is known to be a very important one. *Supposing* that chlorophyll is not directly related to the action of light in exciting the decomposition of carbonic acid by the true living substance of green plants, there are yet other activities of the protoplasm of the plant-cell to which it may be related. Engelmann has recently shown that luminous rays (independently of the obscure heat-rays) cause sudden contraction of protoplasmic organisms devoid of chlorophyll or other pigment, whilst the expansion of Ethalium on the surface of tan in the dark, and its contraction beneath the tan during sunlight, is a well-known phenomenon capable of experimental demonstration. The action of solar rays other than those highly endowed with the property of exciting thermal vibrations upon the living tissues of both animals and plants appears to be more general than has been usually admitted,[1] and due to a direct influence upon the protoplasm of living cells. This being the case, it is not surprising that, supposing the active agent in the decomposition of carbonic acid in green plants to be the protoplasm itself, that activity should be excited by the same part of the spectrum which excites the human retina. At the same time it would not be surprising that other specific chemical activities should be promoted in protoplasm by the incidence of luminous rays, and it may well be that chlorophyll has a relation to these activities rather than to the decomposition of carbonic acid.

It is here that the important suggestion of Prof. Pringsheim (*see* NATURE, vol. xx. p. 86), based on very simple but careful observations, comes in. The *respiration* of the plant-cell is promoted according to these observations by the action of light. Intense sunlight in the presence of oxygen gas causes the chlorophyll of a plant-cell (as watched with the microscope), to oxidise and disappear. Similarly it causes decomposition and disruption of the protoplasmic portion of the cell. Ultra-red rays have not this effect, and extreme red rays have it but feebly, whilst the more refrangible rays, even to an extreme distance in the blue, exhibit it powerfully. Here then is a chemical action taking place in the plant-cell under the influence of light, and in this case the rays which are active appear to be more nearly coincident with those absorbed by chlorophyll than in the case of CO_2 decomposition. It does not appear that the oxidising process is non-existent in the absence of light, but merely that it is far more active in the presence of light. Accordingly Prof. Pringsheim suggests that the true function of chlorophyll is, by its general absorbent action on light, to protect the protoplasm of the cell from this excessive oxidation, and especially to protect the protoplasm of the chlorophyll corpuscles. Oxidation being thus entirely or nearly entirely arrested in the chlorophyll corpuscles, whilst proceeding in a lessened degree in the general protoplasm of the cell, the protoplasm of the chlorophyll corpuscles is at liberty *under the influence of those rays of light which are allowed to pass by the chlorophyll* (the very reverse of former suppositions on the subject) to decompose carbonic acid and synthesise the elements of starch (or of hypochlorin). And we know, as stated above, that the rays of light allowed to pass by chlorophyll are those which are the most efficient in the excitation of this activity.

Prof. Pringsheim's hypothesis thus reconciles in a most ingenious manner the concomitance of chlorophyll and CO_2-decomposition with the inactivity of that body as isolated and the apparent irrationality of its absorption-phenomena.

3. That so special an activity as the decomposition of carbonic acid and synthesis of the elements of starch is due to protoplasm itself and not to a body which, like chlorophyll, appears to be of a *comparatively* simple chemical nature, is probable on *à priori* grounds.

Throughout the organic world—so far as our knowledge goes, and it may be admitted that it does not go very far—the more complex chemical processes connected with nutrition on the one hand and secretion on the other appear to be carried on directly under the influence of the living substance of cells. We know of no formed-products similar to chlorophyll which stand between the gland-

[1] The cases of "sun-burn" produced by the glare of the electric light without any accompanying sensation of heat, related both by Prof. Tyndal and Mr. Norman Lockyer, are in point. Further also the remarkable influence of exposure to sunlight on the phosphorescence of Beroë, as recorded by Prof. Allman, *Proc. Roy. Soc.* Edinburgh, 1862.

protoplasm of animals and the material which they break down into secretions, such as the components of bile, or such as the hydrochloric and sulphuric acid of other glands. But still more important are the examples of elaboration and synthesis presented by some of the lowest organisms. Without chlorophyll, or, as far as we have any ground for conclusion, any such intermediary, the protoplasm of the Bacteria acts upon ammonium acetate so as to build up carbon, nitrogen, hydrogen, and oxygen into an albuminoid compound like itself. Such action appears to be the specialty of protoplasm, for even when a share of the work is attributed in the green plant to the green pigment chlorophyll, yet we have to come back to protoplasm to finish the job and do the really difficult feat of combining carbo-hydrates and ammonia. By dismissing chlorophyll from the operation altogether we do not add materially to the capricious many-sidedness of protoplasm. Here it can take carbon from carbonic acid and nitrogen from ammonia, there it can do with nothing less than an acetate, there again it must have a tartrate at least, and in a fourth example it perishes without albumens.

If the green pigment has been misrepresented in the foregoing indictment, and if it really is something more than a screen for protoplasm, its character must be re-established by direct demonstration of its capabilities. The facts, as at present in evidence, look very much indeed as though chlorophyll had been assigned a position of unmerited dignity.[1] E. RAY LANKESTER

[1] Mr. Vines suggests that if Pringsheim's view be correct, then it might be possible by aid of an artificial chlorophyll screen to excite the protoplasm of fungi or even of animals to the decomposition of carbonic acid. This seems to me unlikely on account of the definitely characteristic chemical activities acquired by protoplasm in different organisms. *But it certainly would be worth while trying the experiment with an etiolated green plant and an artificial chlorophyll screen.* The experiment would be decisive.

HANDBOOK OF BOTANY

Handbuch der Botanik. Bearbeitet und herausgegeben von Dr. N. J. C. Müller, Professor in Münden. Erster Band, Erster Theil. Anatomie und Physiologie der Gewächse. (Heidelberg, 1880: Carl Winter's Universitätsbuchhandlung.)

THE volume before us is the first of a work which is to treat of all the departments of the science of botany. In his preface Prof. Müller explains that he has been led to undertake this very serious task by the conviction that unity of design is the first essential in an educational work such as this is to be, and that this unity cannot be attained unless all the parts of it come from the same hand. Possibly his estimate of the value of this unity may be correct, but it must not be forgotten that the division of a labour such as this secures one very important advantage, namely, the complete treatment of each of the separate parts, and this may after all be quite as important as the unity of design.

These considerations naturally recall to memory the handbook which was planned on so magnificent a scale by Hofmeister. That work is still unfinished, and long periods of time intervened between the publication of volumes of it by the different authors, so that, as it is, the work necessarily exhibits but little unity of design, and must therefore, from Prof. Müller's point of view, possess comparatively little educational merit. As a matter of fact, however, the deficient unity is hardly noticed, for the parts are so complete in themselves that they can stand alone, and are of permanent value as books of reference.

We will now proceed to form an estimate of the success which has attended Prof. Müller in the execution of the first part of his plan. In this volume he treats more especially of the physiology of plants, giving also some account of their coarser anatomy, and he does so with so much detail that he fills more than six hundred pages. It will perhaps be well to defer any remarks upon the latter subject until it has been treated, as Prof. Müller promises, in a more complete manner in subsequent volumes.

With regard to physiology, then, it must be admitted that Prof. Müller's work is an elaborate one, and that it gives evidence of much labour and thought; but yet the result cannot be regarded as other than unsatisfactory. It contains a great deal of information, some of it of a very recondite description, but it is not arranged in a clear and logical manner so that the student can readily grasp the facts and appreciate their mutual relations. There is a want of proportion or perspective about it, and the result is that the fundamental facts do not stand out clearly from those of secondary importance. The mode of stating the facts is not always all that could be desired. On p. 1, for instance, protoplasm is spoken of as being *fluid* (*flüssig*), a mode of describing its consistence which is generally considered to be inaccurate. But the most serious defect in the book is the want of definite statements of the conditions under which the more important vital phenomena take place. There is a sort of vagueness about Prof. Müller's account of these which will prove distressing to any student who reads his book. For example, let us take the discussion of the mode of growth in surface of the cell-wall. On p. 100 there is a very brief statement of the theory of growth by intussusception; on p. 146 there is an account of Nægeli's theory of the structure of the cell-wall; but when we turn to p. 170, where the account of the actual growth of the cell-wall is given, no reference is made to either of these theories, which are generally regarded as being of the first importance in explaining the process of growth. Then as to the turgid condition of the growing cell: this is certainly mentioned on p. 170 and on p. 193, but no hint is given of the means by which this condition is produced and maintained, or of its significance in the process of growth. It is evident that a student would have considerable difficulty in obtaining anything like a clear idea of the mode of growth in surface of a cell wall from Prof. Müller's account of it.

Again, there is no clear distinction made, in Prof. Müller's account of the circulation of liquids in the plant, between the slow movement of solutions of nutritious substances and the rapid movement of water in connection with the process of transpiration; and the paths along which the liquids travel in these two movements are by no means clearly traced. The recent important researches of Sachs and of von Höhnel on this subject appear to have been overlooked.

Further, in discussing the decomposition of carbonic acid by chlorophyll under the influence of sunlight, Prof. Müller makes no clear statement as to which of the